Towards Breakout Boards & Prototype Kits for Force-Responsive Displays

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Our research focuses on force-augmented interactions on deformable displays, requiring the design and construction of interactive surfaces that can (1) dynamically alter their stiffness; (2) allow users to apply force to physically `push through' them and (3) apply force back on the users' fingers. However, these displays are complex to fabricate, limiting their availability. In this position paper, we propose force-responsive display breakout boards, which would provide off-the-shelf, self-contained deformable surfaces that can be used to study force-responsive interactions in various settings, including workshops or user studies. These boards would realise the availability and simplicity of breakout boards and prototype kits in studying force-responsive displays. We explore the challenges associated with designing and fabricating force-responsive displays, propose key features and functionalities, and discuss two concepts for possible examples of such boards, highlighting the potential uses and significant benefits this type of board could offer to the HCI community.

CCS CONCEPTS • **Human-centered computing → User interface toolkits; Haptic devices.**

Additional Keywords and Phrases: electronics, prototyping, toolkits, physical computing, deformable interfaces, non-rigid interactions

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1 INTRODUCTION

The FORCE-UI project[1] aims to augment traditional display devices with force interactivity to radically transform touchscreen-based interaction and increase interaction expressivity. A key part of this project is to leverage advances in fields such as mechanical and electrical engineering, soft robotics, and smart materials, with the goal of bringing together three force modalities: deformable force input, and both resistive and kinetic force feedback, in a display device. Designing and fabricating a device with these force input and output capabilities poses significant engineering challenges which require a high level of technical expertise, specialist lab spaces, and bespoke equipment. This creates significant barriers to entry, preventing non-specialist groups from studying the field while also limiting the scope and speed of prototyping and development.

The workshop organisers identify three main paradigms for electronics prototyping "(1) discrete electronic components, (2) breakout and development boards, and (3) integrated toolkits consisting of modules specifically designed to work together"[2]. These paradigms describe the current state-of-art for traditional electronics prototyping, though the same does not apply to

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1 ERC FORCE-UI: https://cordis.europa.eu/project/id/853063

2 Beyond prototyping boards: https://electrofab.prototyping.id/assets/Beyond_Prototyping_Boards.pdf

prototyping force-responsive displays. Instead, this is currently mostly restricted to paradigm 1, where the designer requires significant expertise and knowledge to construct a system from discrete parts, components, and materials. In this position paper, we propose how the development of force-responsive displays can be expanded towards paradigms 2 & 3, discuss benefits and implications, and propose example uses.

2 PROTOTYPING FORCE-RESPONSIVE DISPLAYS

Force-responsive displays build on the emerging area of non-rigid interactive devices [1] and aim to augment traditional touchscreen displays with force sensing, variable stiffness, and reactive force. There are several notable devices in the literature which fully or partially realise the concept of force-responsive displays, such as inFORCE [5], MudPad [3], Trampoline [2], and ForceForm [9]. Due to the limitations on high-resolution elastic and deformable graphical screens, current force-responsive displays use a projector or separate rigid display to add a graphical output. All of these are complex and impressive engineering achievements, though they use techniques that require expert knowledge and designs, restricting their availability to the wider HCI community.

Prototyping force-responsive devices is non-trivial, as they are designed to deform and sense physical inputs, making them more expressive and interactive while also providing haptic feedback by varying their surface stiffness. We have identified three key challenges based on our experiences of designing and fabricating force-responsive displays.

- **Integrating I/O into Non-Rigid Form Factors**: Traditional sensors and actuators are rigid or flexible, meaning their integration into an elastic device could detriment the physical properties. Expert knowledge is required to select and design suitable device inputs and outputs which will meet the requirements without impacting haptic perception.
- **Overcoming Technical Implementation Hurdles**: Achieving reliable and robust operation is a major complication in the fabrication, requiring specialist skills such as circuit board design, knowledge of discrete electronics and low-level programming.
- **Knowledge and Resource Restrictions**: Building devices, which call on a disparate range of techniques, place a focus on the need for inter-disciplinary teams, with individuals who have access to specialist lab spaces and technical equipment and are suitably trained to work with these technologies safely.

These challenges highlight the difficulties in creating force-responsive displays and we believe research can be accelerated and made more accessible by following the direction taken in electronics prototyping, towards self-contained boards and kits.

3 VISION FOR FORCE-RESPONSIVE DISPLAY BOARDS

New breakout boards and prototype kits used to design and build interactive devices have drastically reduced the barrier to entry for prototyping with electronics, radically changing not only what can be built but who can build them. As a result, this has opened the space to new groups such as researchers, educators, artists and industrial designers who all bring unique perspectives and insights.

We propose a force-responsive display board, which would do the same for force-augmented displays, integrating force inputs and outputs into a single standalone device. As force-responsive displays can be created using various approaches, such as elastic sheets, soft pneumatic devices, or smart materials, each with different advantages and disadvantages, this requires a diverse range of force-responsive display boards. To fully realise the potential, we have identified key features:

- **Seamlessly Incorporating Input & Output**: The required inputs and outputs for the device to be used should be integrated into the system without impacting the possible interactions.
- **Complete & Self Contained**: The board should be a self-contained system including control systems, power management, signal processing, microcontroller compatibility and appropriate libraries and code examples.
- **Availability & Open-Source**: Deformable Breakout boards should be as widely available as possible and open source, including the code, PCB design and fabrication. The approach taken for devices such as the Arduino should be followed, with a fully assembled board cheaply available, along with the components and design being open-source.

4 CONCEPTS FOR FORCE-RESPONSIVE DISPLAY BOARDS

The authors have built upon their previous experiences and drawn on notable examples in the literature to highlight the potential of force-responsive display boards.

4.1 Elastic Force-Responsive Input Surface

Sheets of non-rigid materials (e.g. elastic, fabric and latex) are widely used to achieve force-responsive surfaces [2, 6, 8]. Though these types of surfaces only partially enable the full vision of force-responsive displays, sometimes lacking graphical outputs or dynamic stiffness, they provide an expressive surface, enabling interactions that are not possible on other types of displays and can even be developed into a mobile form factor. An elastic force-responsive input surface opens up the study of these complex and expressive interactions to a wide range of researchers and designers.

The surface would consist of an elastic sheet held inside a rigid frame, which can capture and transmit user inputs. This could be implemented in two forms, 1) a prefabricated device, similar to Trampoline [2], which can be connected to a microcontroller, and the force input can be used to interact with applications, and 2) an adjustable frame, which can be re-sized to fit custom material samples and calibrated to capture user inputs accurately, enabling anyone to explore different forms and materials. This approach mirrors that taken by existing prototype kits, such as the Bare Conductive Touch Board Pro Kit[3], which has printed sensors that can be connected directly to the controller as well as the components for users to build and explore at will.

A flat elastic force-responsive input surface, if made widely available and fully self-contained, could enable researchers to conduct workshops investigating force-responsive inputs with diverse groups of users while also allowing groups previously excluded, such as artists or educators, to explore "push-through" interactions in the context of their work.

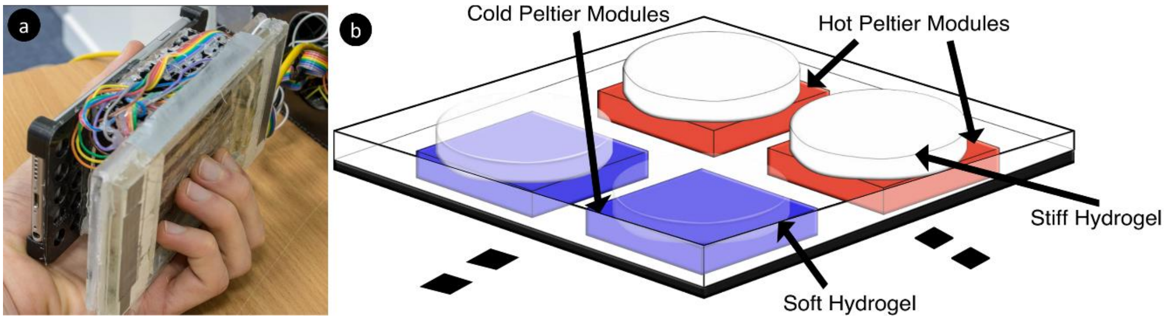

Figure 1: Figure 1a) is an interactive device, previously created by the authors, which used heat dependant hydro-gels to dynamically change the surface stiffness, and could be realised as a smart material swatch. b) The devices used Peltier modules set under the hydrogel. The red Peltier module shows stiff gel in a fully white state and the blue Peltier shows soft gel in a transparent state.

4.2 Smart Materials Swatches

Smart Materials have been used to create force-responsive interfaces with novel and dynamic properties, being used for applications such as paint mixing simulation [7], dynamic buttons [4], or medical training [9]. Developing devices that leverage smart materials is technically challenging and requires expert knowledge and complex and expensive labs, greatly restricting the exploration of devices that utilise these technologies.

Smart Materials are also technologically complex to control and integrate into existing systems, requiring other outputs, such as temperature, pressure, light, electric current or magnetic fields, to alter their property. Furthermore, they do not lend themselves to sensing user inputs, increasing the complexity further. We propose "Smart Material Swatches" which would be self-constrained units which would be similar in size and usability to a touchscreen breakout board[4]. These boards would have a sealed smart material pouch, safely enclosing the gel or fluid, layered on top of a controller, creating the necessary environmental change to alter the properties of the material, as well as capture user inputs applied to the board. Users could access a selection of different boards, which control different smart materials and swap out pouches for materials with the same control method. These swatches should facilitate integration into other systems, such as the back of mobile devices, as shown by Steer et al. [7]. By connecting a microcontroller, simple applications could be created to change the material properties in response to application status or user input, exploring how changes in surface stiffness can provide force feedback. As the boards would be open source, developers can adapt the design to meet more specific requirements as their project grows or new materials are brought into the deformable interface field.

[3] Touch Board Pro Kit: https://www.bareconductive.com/products/touch-board-pro-kit

[4] Adafruit Touchscreen Breakout: https://learn.adafruit.com/adafruit-2-8-and-3-2-color-tft-touchscreen-breakout-v2

5 CONCLUSION

In this position paper, we propose the concept of force-responsive display breakout boards, which increases the availability and reduces the development barriers for the emerging field of force-responsive displays. We highlighted the current barriers to entry for studying force interactions on deformable surfaces due to the challenges surrounding design and fabrication, which limit who can access these devices and the rate at which studies and exploration can be conducted. Based on this, we introduce starting features for future force-responsive display breakout boards that ensure their usability and availability. Aiming to radically change who could access and study force-responsive displays, enabling new groups to explore the interaction potential and use cases that have not yet been considered. Using these features, we applied them to two concepts from our experiences prototyping for force-responsive displays and outlined how the breakout boards could be utilised in HCI research projects.

Overall, we believe that force-responsive breakout boards hold the potential to accelerate research into force-augmented interactions, allowing a wide range of groups of people to explore novel interaction opportunities, prototype new devices, and expand capabilities through Open-source frameworks. In joining the workshop, we aim to expand on these concepts and uncover new possibilities for our use cases while also engaging and learning from like-minded attendees' experiences to advance what is possible with breakout boards.

6 AUTHOR BIOS

James Nash: Is a PhD Student studying force-augmented interactions on deformable displays. His research combines novel engineering techniques, drawing on advancements in soft-sensing and actuating along with rapid prototyping to create deformable devices, which enable the exploration of interaction potential of soft deformable surfaces.

Cameron Steer: Is a Postdoc at the University of Bath. His research focuses on the development of tangible, deformable and shape-changing interfaces that add a physical layer to our digital worlds. In particular, his research goals centre around developing novel prototypes, extending understanding of user interaction techniques and generating use-cases.

Teodora Dinca: Is a PhD Student studying novel ways of constructing deformable displays. She is focusing on the use of smart materials towards creating interface prototypes that allow varying types of interactions.

Christopher Clarke: Is a Lecturer (Assistant Professor) in Human-Computer Interaction in the Department of Computer Science at the University of Bath. His research includes novel interaction techniques, touchless input modalities, wearable technologies, and interaction in extended reality environments.

Jason Alexander: Is a Professor in Human-Computer Interaction in the Department of Computer Science at the University of Bath. He has a particular interest in developing novel interactive systems that straddle the physical-digital interface. His recent work focuses on the development of novel force-responsive devices and shape-changing interfaces.

REFERENCES

[1] Alberto Boem and Giovanni Maria Troiano. 2019. Non-Rigid HCI: A Review of Deformable Interfaces and Input. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19). Association for Computing Machinery, New York, NY, USA, 885–906. https://doi.org/10.1145/3322276.3322347

[2] Jaehyun Han, Seongkook Heo, Jiseong Gu, and Geehyuk Lee. 2014. Trampoline: A Double-Sided Elastic Touch Device for Repoussé and Chasing Techniques. In CHI '14 Extended Abstracts on Human Factors in Computing Systems. ACM, Toronto Ontario Canada, 1627–1632. https://doi.org/10.1145/2559206.2581252

[3] Yvonne Jansen, Thorsten Karrer, and Jan Borchers. 2010. MudPad: A Tactile Memory Game. In ACM International Conference on Interactive Tabletops and Surfaces (ITS '10). ACM, New York, NY, USA, 306–306. https://doi.org/10.1145/1936652.1936734

[4] Viktor Miruchna, Robert Walter, David Lindlbauer, Maren Lehmann, Regine von Klitzing, and Jorg Muller. 2015. GelTouch: Localized Tactile Feedback Through Thin, Programmable Gel. In Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST'15). ACM, New York, NY, USA, 3–10. https://doi.org/10.1145/2807442.2807487

[5] Ken Nakagaki, Daniel Fitzgerald, Zhiyao (John) Ma, Luke Vink, Daniel Levine, and Hiroshi Ishii. 2019. inFORCE: Bi-directional 'Force' Shape Display for Haptic Interaction. In Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19). Association for Computing Machinery, New York, NY, USA, 615–623. https://doi.org/10.1145/3294109.3295621

[6] Deepak Ranjan Sahoo, Kasper Hornbæk, and Sriram Subramanian. 2016. TableHop: An Actuated Fabric Display Using Transparent Electrodes. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 3767–3780. https://doi.org/10.1145/2858036.2858544

[7] Cameron Steer, Jennifer Pearson, Simon Robinson, and Matt Jones. 2017. Deformable Paint Palette: Actuated Force Controls for Digital Painting. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17). ACM, New York, NY, USA,2936–2943. https://doi.org/10.1145/3027063.3053219

[8] Andrew Stevenson, Christopher Perez, and Roel Vertegaal. 2010. An Inflatable Hemispherical Multi-Touch Display. In Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction (Funchal, Portugal) (TEI '11). Association for Computing Machinery New York, NY, USA, 289–292. https://doi.org/10.1145/1935701.1935766

[9] Jessica Tsimeris, Colin Dedman, Michael Broughton, and Tom Gedeon. 2013. ForceForm: A Dynamically Deformable Interactive Surface. In Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces (ITS '13). ACM, New York, NY, USA, 175–178. https://doi.org/10.1145/2512349.2512807